MONTHLY WEATHER REVIEW

Editor, EDGAR W. WOOLARD

VOL. 70, No. 10
W. B. No. 1373

OCTOBER 1942

CLOSED DECEMBER 2, 1942
ISSUED DECEMBER 31, 1942

A STUDY OF ATMOSPHERIC POLLUTION

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In an earlier paper [1] a description was presented of an improved Owens automatic air filter and associated instruments that had been developed for use in making a survey of atmospheric pollution. The present paper describes the survey in more detail and will offer certain suggestions, based on this experience, for the conduct of other investigations.

The survey was undertaken in an effort to determine the extent to which dust emitted from the chimneys of power houses and gas manufacturing plants within the city contributed to the general atmospheric pollution of the city. There were certain intentional limitations on the original scope while other limitations became apparent as a result of the survey.

In the first place, the study was restricted to the measurement of suspended dust which is here understood to include only solid particles of such size that their settling rate in the atmosphere is not greatly different from the vertical components of air velocity associated with normal turbulence. The measurements of dust concentration were to be determined primarily by the measurement of shade number in the modified Owens recorder, although provision was made, as will be discussed later, for converting the observations to weight loading such as tons per cubic mile. The selection of meteorological data to be used in the survey was, to a considerable degree, arbitrary and restricted to the obvious factors of wind velocity, wind direction, temperature in the shade, and humidity.

The determination of the number of observation stations and their location presented a difficult problem involving the necessity of choosing between a small number of stations with the corresponding increase in cost and the large increase in the complexity and difficulties of the statistical analyses. The final decision was to use eight observation stations located as shown in the outline map, figure 1. Effort was made in the final placing of the recorders to get them at points generally above prevailing roof levels in the area so as to be reasonably free from major erratic variations in wind conditions. The levels of the observation points above sea level and above the street are summarized in table 1.

Since data on wind direction and velocity were required, it was decided to install two Friez recording wind direction velocity stations, designated as A and B in table 1, rather than to call on the Weather Bureau for the special services that would be involved in making promptly available the large number of observations. Data on air temperatures and humidity were obtained from the daily Weather Bureau records.

The dust samplers were adjusted to operate at the hour and half-hour. During the early part of the survey, they were checked at least once a week, and later this interval was extended to about 3 weeks. The records, after removal from the machine, were examined, checked, and marked for identification and then assembled into strips filling a 400-foot 16-mm. motion picture film reel. For measuring the records, the scanner or photoelectric densitometer was placed on a typewriter desk with the control

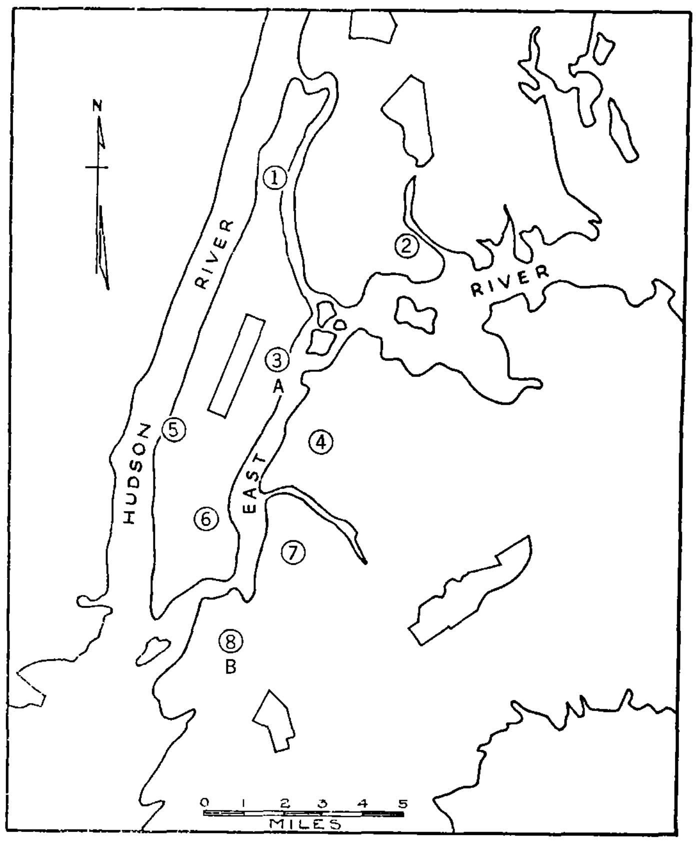


FIGURE 1.—Location of recording stations.

push-button near the keyboard and the meter conveniently located. A tabulating form was arranged with 48 columns—one for each half-hour with one line for each day so that entries were made across the page line by line. Shade numbers were recorded in the nearest unit, although the instrument readings were reproducible to better than one-half unit. With these facilities, an operator after a little experience could measure and enter on the data sheet about 3,000 observations during the normal working day. With eight stations, about three days per month were needed for this phase of the study.

The enormous volume of data—about 200,000 observations of shade number and 50,000 observations of wind

[1] W. F. Davidson and Warren Master—Automatic dust sampling and analyzing instrument for atmospheric pollution surveys—Mo. WEA. REV., Sept. 1941, 69: 257–260.

velocity and direction for an 18 months' survey—made the use of machine tabulating methods almost imperative. Accordingly, meteorological and dust (shade number) data were transcribed to Hollerith cards. One card was prepared for data for each half-hour period with entries showing the shade number for each of the eight stations and the wind velocity and direction for each of the two wind stations and the air temperature in the shade and the humidity. This made a total of 48 cards per day or 1,440 per month—about 1 day's work per month for the key-punch operator.

The various steps by which the cards were put through the sorting and tabulating machine will not be described, as the exact processes are of no immediate interest. Of the many analyses that were tried, only a few gave evidence of useful correlation to be extended to the entire survey.

Typical tabulations are presented here for two representative months, namely July 1939 and January 1940. These are table 2—Daily Station Averages—Suspended Solids Expressed as Mean Shade Number; table 3—Mean Shade Number by Hour; table 4—Mean Shade Number for Each Wind Velocity and Time Distribution of Wind Velocities; table 5—Mean Shade Numbers for Each Wind Direction and Time Distribution of Wind Direction. Other data were prepared in the form of charts which will be discussed later.

Examination of any of the tables emphasizes immediately the enormous difficulties in the way of interpreting the data. Variations from day to day and from hour to hour are often large and have no simple explanation. The futility of attempting to make sound conclusions on the basis of a limited number of observations, especially if they are made at a single location, thus becomes more apparent.

Figure 2 shows a portion of a chart plotting daily average values of shade number, together with wind velocity and direction and daily mean temperature data. It is evident that any relations that may exist between these various factors are by no means simple. However, there is a suggestion that there may be a useful correlation between wind velocity and shade number and this is further borne out by the charts of figure 4. In these the data for each month have been plotted on double logarithmic scales. There is a clearly indicated relation that the shade number (dust concentration) varies inversely as the square-root of the wind velocity. The correlation coefficient is 0.989. The explanation for this will probably be found to involve atmospheric turbulence, but we have not attempted to study the problem in detail.

Several attempts were made to make use of this empirical relationship in the adjustment of other data, but it did not seem practical to go beyond the arrangement of the data in table 5 where distinction is made between shade

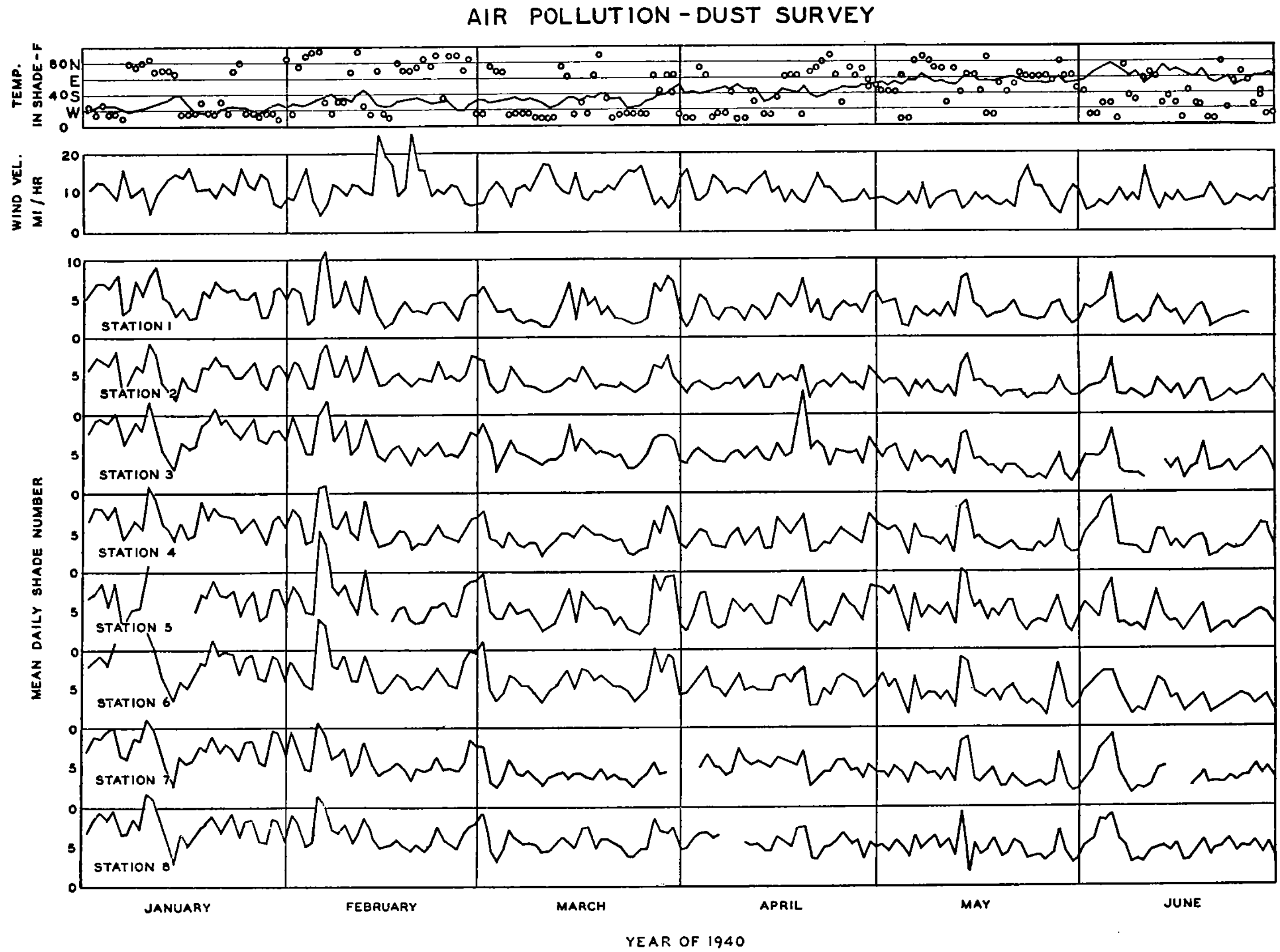


FIGURE 2.

number observation when the wind velocity was less than 7.5 miles per hour and observations when the wind velocity was greater than 7.5 miles per hour.

Since the chief purpose of the survey was to determine the extent to which specific power stations might contribute to the general atmospheric pollution, further analysis was necessary. Several earlier investigators had made use of maps on which they plotted some function of dust concentration and wind velocity, such for instance as the "shade-miles" used in some earlier studies of the New York area. The typical charts of figure 3, for the months of July 1939 and January 1940, show a somewhat different method of analysis. In these, an outline map is used as a base with wind velocity and shade number, points for low wind velocities lie outside those on high wind velocities. Extension or bulge of the polygon in any direction indicates that some principal sources of atmospheric dust lie in that direction, but great caution must be exercised in drawing any conclusions for the data as presented do not take any account of the relative duration of the specific conditions.

To illustrate one way in which these charts have been used, consider the data for January 1940 and assume the condition of a north wind of less than 7.5 miles per hour. Shade number for station 1 is 6.9 and we assume that this represents the concentration of dust originating in the area north of this station. Now, if we follow the chart to

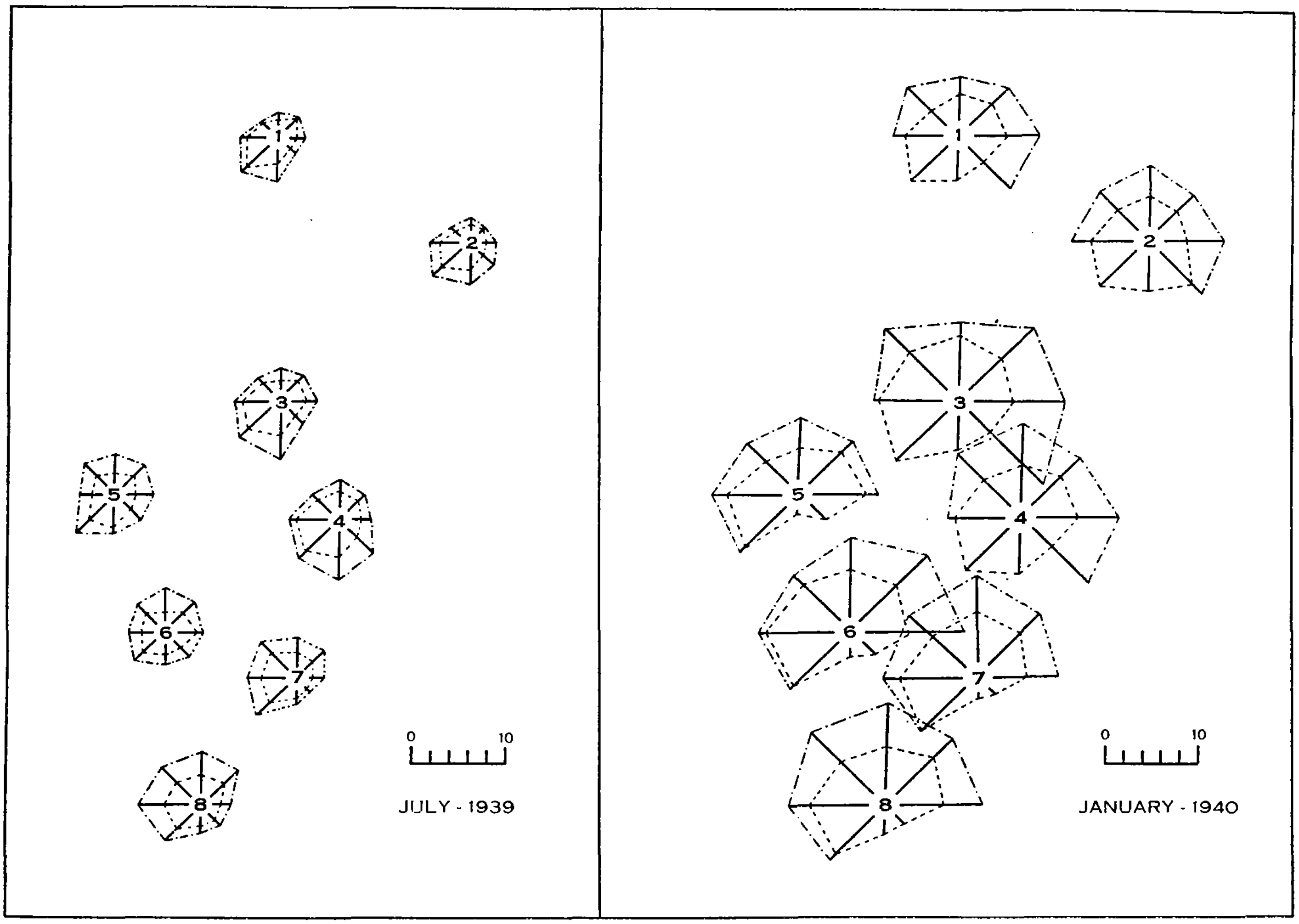


Figure 3.

the location of the various observation stations indicated by appropriate numbers. Radial distances are then plotted from each central point in such a way that the length is proportional to the average shade number, using the scale shown on the chart, while the wind is from the direction of the radius and is either less or greater than 7.5 miles per hour. Thus, for January 1940, table 5 shows that at station 1, north winds above 7.5 miles per hour resulted in a mean shade number of 5.0. This is plotted as a radius of 5 units long north (vertically) from station 1. The other radial lines are similarly plotted and the ends of these are connected by a series of straight lines forming closed polygons. Where no line is drawn it indicates that there were no observations for that condition. As would be expected from the relation between the south, we come to station 3 and observe from the chart that the shade number is 8.5 or an increase of 1.6 numbers above that at station 1. Accordingly, it would appear that an amount of dust equivalent to 1.6 shade numbers had been released to the atmosphere in the zone between stations 1 and 3. Going still further south, we reach station 7 and observe that the shade number has there risen to 11.3 and, again, we assume that dust equivalent to 2.8 shade numbers has been released in the zone between stations 3 and 7. All this makes a consistent story. Now assume the case of an east wind and take stations 4 and 5. At station 4, the shade number is 10.9 while at station 5, it is 8.5 or a reduction of 2.4 shade numbers, which would indicate that dust, instead of being released in the atmosphere in this part of the city, is being precipitated out. Such a situation is undoubtedly possible, but the fact that it can exist must serve as a reminder that caution, and a very considerable measure of judgment, are necessary for the interpretation of the data.

Another approach to the problem of analysis and interpretation is to take the chart of figure 5 which shows the hourly variation of mean shade number for each month. (In plotting this the time is prevailing time.) It will be noted that for every month there is distinct maximum occurring near 8 a. m. and that there is a second maximum, but not quite as high between 6 and 8 a. m. in the winter months. In the summer months—June to September—the low point for the day occurs between 4 and 6 p. m. Having in mind the correlation between shade number and wind velocity previously mentioned, it is possible to adjust the observed data to correspond to the average wind velocity. This has been done and it has been found that it reduces the morning maximums by a little less than 0.8 shade number (for winter) and that it increases the summer afternoon minimums by about 0.2 shade number. Clearly the effects of wind velocity afford only a partial explanation.

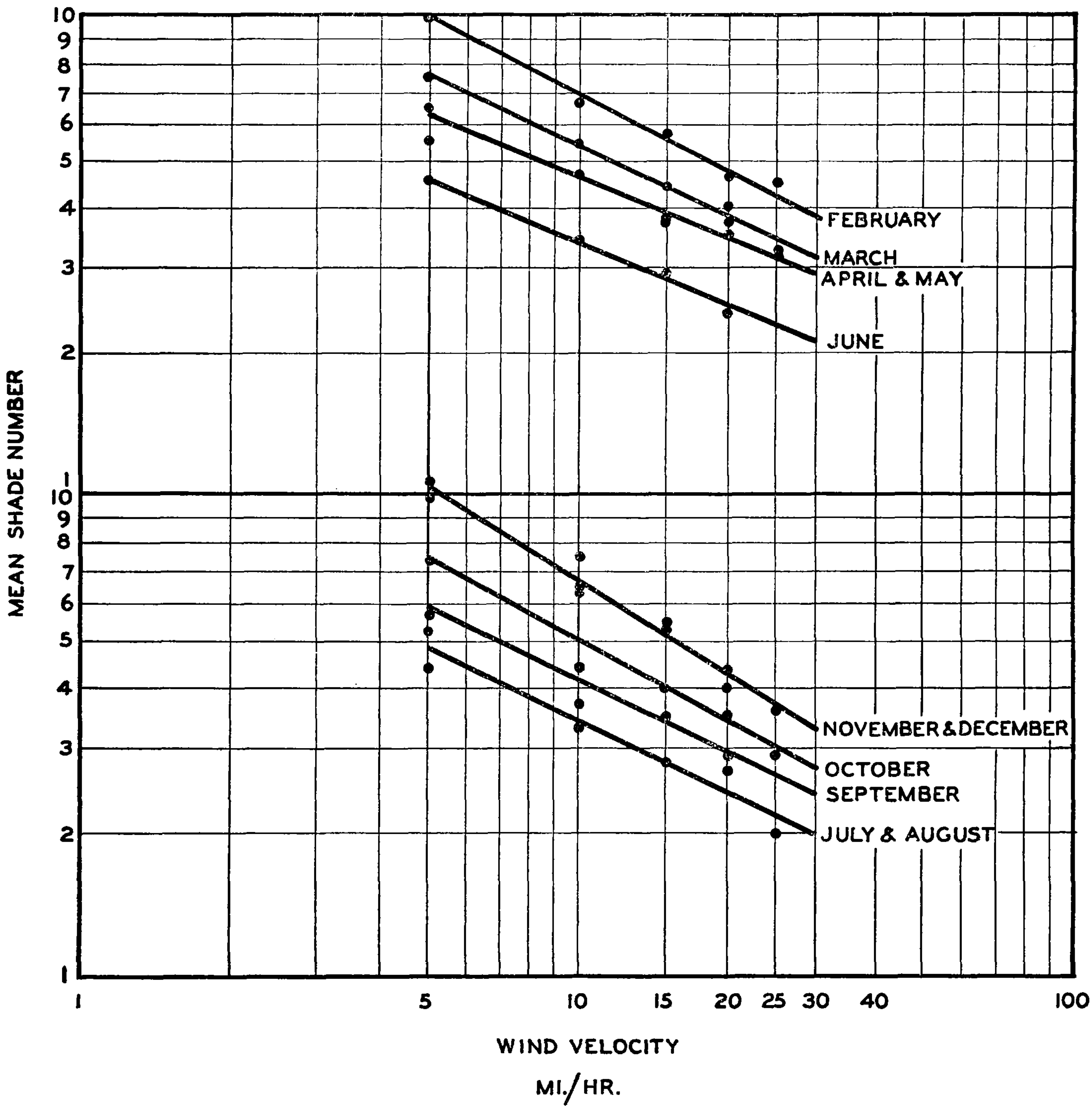


FIGURE 4.

In figure 6 there are plotted the shade number curves for January and July and corresponding representative week-day load curves of the electric utility generating stations. An almost startling feature is that from mid-

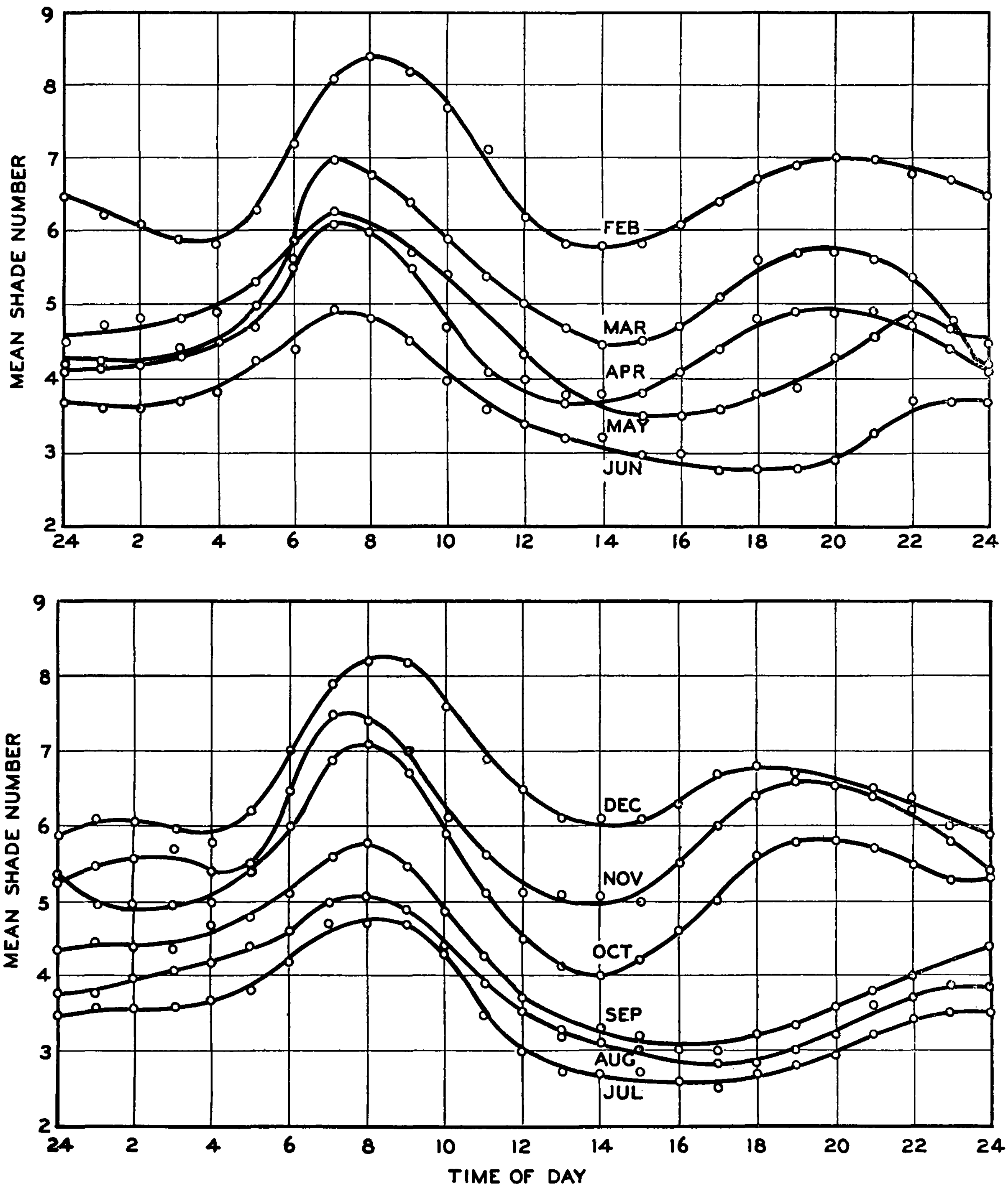

MEAN SHADE NUMBER
FEB
MAR
APR
MAY
JUN
DEC
NOV
OCT
SEP
AUG
JUL
TIME OF DAY

Figure 5.

night until 3 in the afternoon and again from 9 in the evening until midnight—or during about 18 hours out of the 24 hours in a day—the winter and summer loads do not differ by a factor or more than 1.5 and in most cases by a factor of less than 1.1. On the other hand, during these same hours the shade numbers differ by a factor of from 1.5 to 2.1.

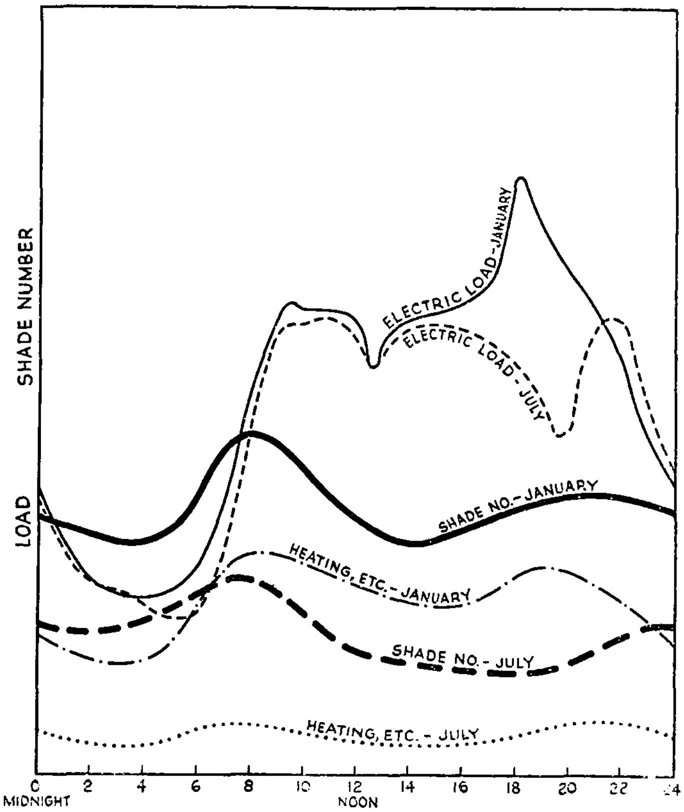


FIGURE 6.

No accurate data are available on the character of load curves for domestic house-heating, apartment and hotel-heating, water-heating and incinerators, but some estimates, based in part on known load curves for gas-heating and district steam, are shown as curves in figure 6. The form and relative magnitude of these match the shade-number curves considerably more closely than do the electric system load curves.

At this point, it should be pointed out that load alone is not an adequate measure of the dust emission from power station chimneys, particularly where stoker firing is used. The load on the operating boilers and the rate at which it is changing must be taken into account. As an illustration, take figure 7 which shows the boiler load during a 12-hour period and the cinder loading in the stack (this includes cinder and dust). Between 4 and 6 p. m. the steam output increased by a factor of 1.5 (50 percent) while the cinder loading increased by a factor of 3.0 (200 percent) and the total cinder and dust emission increased by a factor of 4.5. Then between 6 and 9 p. m. the load decreased by a factor of 0.85 (15 percent) while the cinder loading decreased by a factor of 0.60 (40 percent). This case should not be considered as more than an illustration of what may happen because other data show for some stations an almost complete independence of station output and dust loading. On the other hand, when it is realized that these observations were obtained on an installation which included cinder and dust catchers that were considered as among the best available at the time they were purchased, some idea may be gained as to the possible performance of installations without dust eliminators of any kind.

Numerous analyses were made to determine any corelations existing between shade number and temperature or humidity. In no case was any useful correlation found. Further, the results were such as to indicate little justification for additional investigations in this region.

It would serve no useful purpose to examine the results of this survey in much more detail, as they are applicable only to a particular area and time. However, before proceeding to consider suggestions for future surveys, it may be helpful to offer some general conclusions.

1. The predominant factor influencing atmospheric dust concentration in the city is human habit in the use of fuel—chiefly fuel used for heating.
2. Dust concentration varies inversely as the square root of the wind velocity.
3. The influence of wind velocity on atmospheric dust concentration is much greater than the influence of temperature per se—that is, during a week the day-to-day variations of dust concentration depend more on wind velocity than on mean daily temperature.
4. There is a seasonal variation of atmospheric dust concentration that corresponds to variations in fuel use for heating.
5. The contribution to the general atmospheric pollution of dust emission from power stations is not great enough to be measurable by the methods used in this survey.

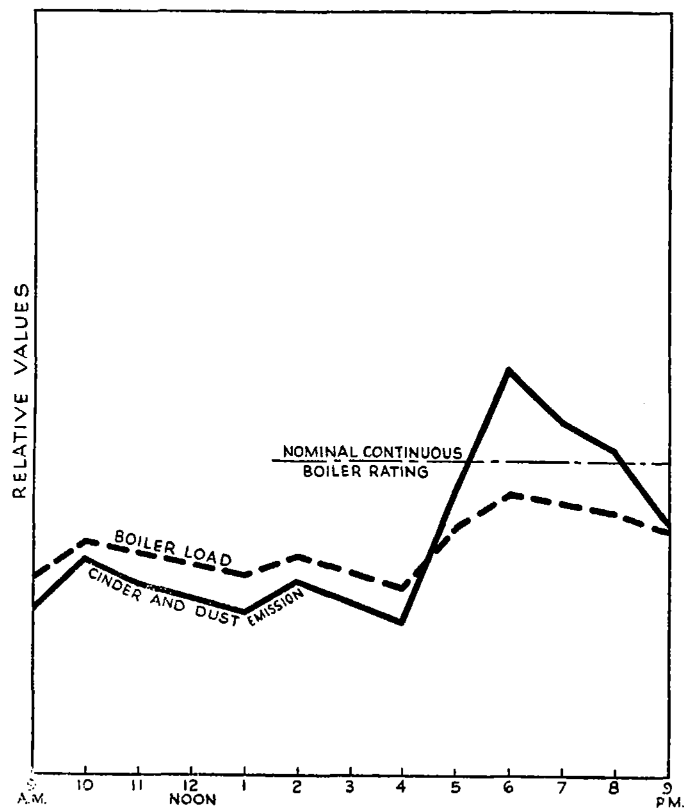
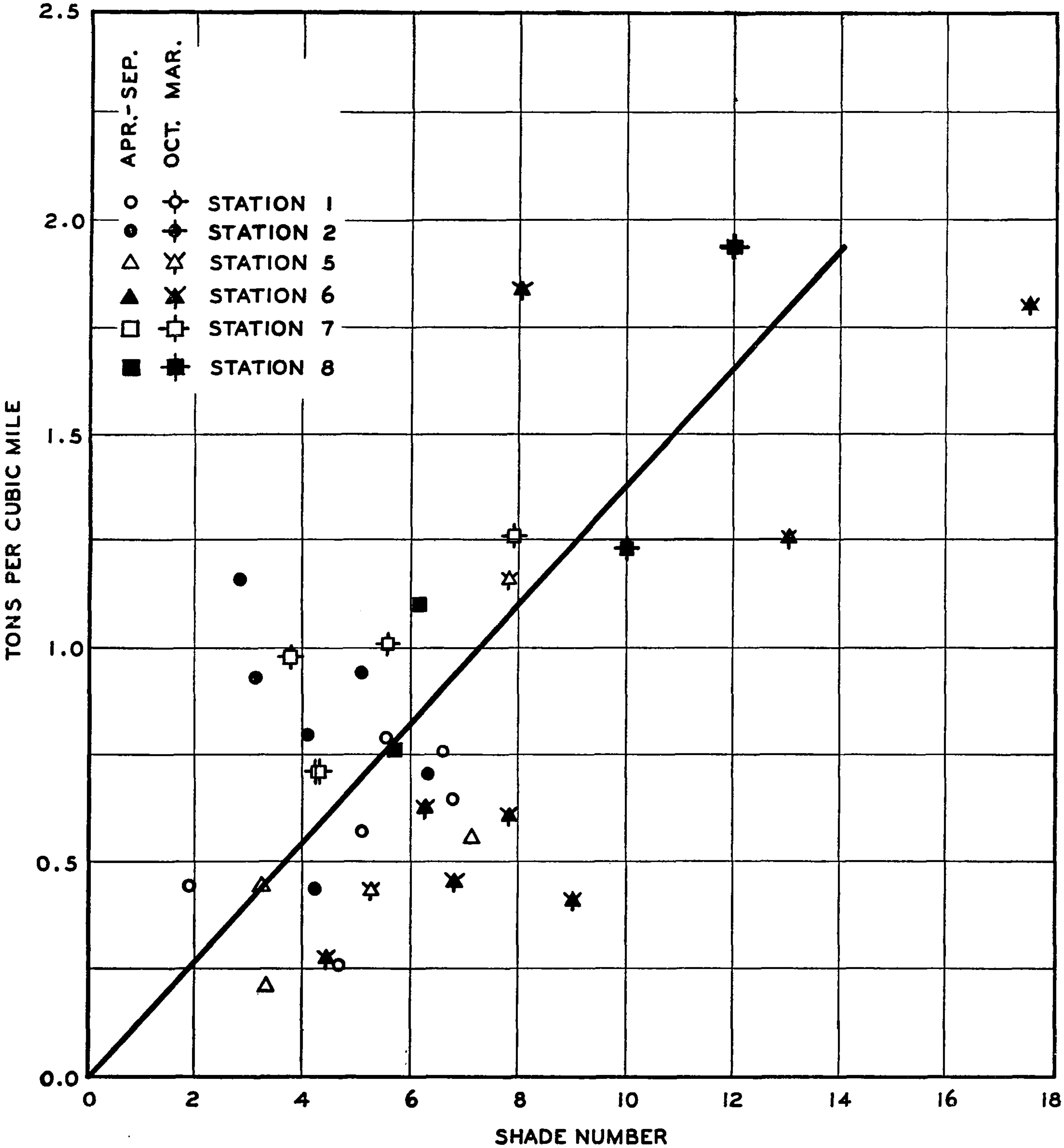


FIGURE 7.

Experience with the survey has emphasized—if that were necessary—the extreme complexity of the atmospheric pollution problem, and it has also shown how



2.5
2.0
1.5
1.0
0.5
0.0
TONS PER CUBIC MILE
APR.-SEP.
OCT. MAR.
STATION 1
STATION 2
STATION 5
STATION 6
STATION 7
STATION 8
0
2
4
6
8
10
12
14
16
18
SHADE NUMBER

Figure 8.

incompletely many of our ideas are formulated. The remaining part of this paper will be devoted to some discussion of a few of the many problems.

As a start, what do we mean by atmospheric pollution? Is it cinders, or dust (in the sense that the term is used in this paper) smoke, or gases other than the "normal" components of air, or the sum of all or a group of them? Why do we call it "pollution"? Is it because it reduces sunlight, or because it absorbs ultra-violet radiation, or because it soils window draperies, or is it because of some other reason? The writer, for one, does not know the answers, but for the purpose of the survey he made a deliberate choice.

Some of the reasons may be of interest. Cinders and coarse dust generally constitute a relatively local problem; dust and the sooty particles from smoke travel far, certainly have some effect on light absorption, and probably are responsible for most of the soiled window draperies. Furthermore, Owens has developed one method for measuring dust. The possibility of bad effects from gases was recognized, but the difficulty of measurement by automatic instruments for a long-time survey seemed too formidable a hurdle to attempt.

Volumes might be written about methods for measuring dust but up to the present time the Owens filter is the only one that can be considered as adaptable to survey use where automatic operation is necessary. The original observation is based on the discoloration or darkening caused by the deposition of the dust on the white filter paper. Owens showed, by an extended series of carefully controlled experiments that, for the types of dust (and smoke) with which he was chiefly concerned, there was a sensibly constant linear relation between "shade number" and dust concentration expressed in units such as "tons per cubic mile." Whether or not it is desirable to make use of this and convert the observations into loading or concentration must depend on two factors. First, is whether or not the conversion factor is sufficiently constant and second, is whether or not concentration is more significant than shade number.

To answer the first of these questions, our survey included tests in which measurements of shade number were made while drawing a large sample (300 to 500 cubic feet) of air through a fitted glass filter where it was collected in sufficient quantity to be weighed on a precision balance. The results are shown in figure 8. The observed points scatter quite widely, but a straight line has been drawn as indicated, having the equation:

$$\text{Concentration (tons per cubic mile)} = 0.14 \times \text{shade number}$$

The correlation coefficient is 0.88, but individual observations depart from the equation by a factor of 3.

To answer the second question, we must first decide what characteristic of dust is most objectionable. It is submitted that it is soiling or dirtying from dust that is the source of most complaints from the public. And further, a new question is propounded: to what extent is dust concentration, when measured in units such as "tons per cubic mile," related to reduction in daylight or ultraviolet radiation? Until an authoritative answer can be given it would seem dangerous to assume that there is a close relationship. It is hoped that studies contemplated by the Weather Bureau will yield the answer. Possibly investigations in connection with general smoke abatement programs could be so planned as to provide useful information.

Another aspect of the dust measurement problem is that of the best location for observing or sampling stations. In our survey, we made the deliberate choice of going to locations above the general roof levels in the neighborhood. This was done in expectation of getting a sample more representative of general atmospheric conditions and hence more likely to show the influence of dust from the power stations. On the other hand, it means that the samples included less of the dust picked up from the streets and roof-tops, which may be an important factor in the total dust at the level of living quarters. Before a final answer is given, especially if it is to be incorporated into a recommended practice for making atmospheric pollution surveys, it would seem essential to study the variations in dust concentration with height above street level for typical city conditions.

Another suggestion is that a strong effort be made to secure data on dust for rural areas near large cities but far enough removed from them to have approximately the same wind and humidity conditions. When such data become available, it will be possible to make a much better estimate of the causes and sources of dust in the cities.

Still another important gap in our knowledge is that caused by our almost complete ignorance as to the composition of the dust. This applies whether it be the physical characteristics such as particle size, particle shape, density or color, or whether it be by the chemical characteristics such as composition. The particles are generally far too small to be resolved by the microscope, although some spores and pollens can be identified. Perhaps the new electron microscope will come to our aid. Obtaining samples large enough for chemical analysis, even by micro methods, seems to require efforts more heroic than most are ready to undertake, but the rewards should justify the attempt.

TABLE 1.—*Location and height of dust and wind stations*

	Description	Height in feet above	
		Street grade	Sea level
Dust station			
1	Office building roof	80	240
2	Substation building roof	30	40
3	Factory building roof	140	150
4	Office building roof	120	150
5	Top of gas holder	290	310
6	Office building roof	260	300
7	Substation roof	50	60
8	Office building roof	100	160
Wind station			
A	Factory building roof	160	170
B	Office building roof	220	270

TABLE 2.—*Daily station averages of suspended solids expressed as mean shade number*

July 1939

Station No.	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Weekly average	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Weekly average
	Date								Date							
							1		2	3	4	5	6	7	8	
1	----	----	----	----	----	----	2.9	2.8	2.0	3.1	5.1	4.5	3.4	5.1	4.9	4.0
2	----	----	----	----	----	----	2.8	2.5	2.0	2.8	3.5	4.1	3.6	4.6	4.0	3.5
3	----	----	----	----	----	----	2.3	3.1	2.2	3.3	3.5	4.5	4.9	4.8	3.8	3.9
4	----	----	----	----	----	----	4.1	3.9	3.4	3.9	4.6	5.5	4.2	5.2	4.1	4.4
5	----	----	----	----	----	----	4.4	3.9	3.2	----	----	----	3.1	5.2	4.0	----
6	----	----	----	----	----	----	2.7	2.6	3.1	3.4	3.0	2.9	2.2	3.2	3.1	3.0
7	----	----	----	----	----	----	4.7	3.4	4.1	4.0	3.8	3.2	2.1	3.0	3.5	3.4
8	----	----	----	----	----	----	5.0	3.0	4.9	3.9	3.1	2.9	2.2	3.0	3.9	3.4
Average	----	----	----	----	----	----	3.6	3.2	3.1	3.5	3.8	3.9	3.2	4.3	3.9	3.7
	9	10	11	12	13	14	15	Weekly average	16	17	18	19	20	21	22	Weekly average
1	3.5	4.4	2.1	3.0	2.6	4.4	2.1	3.2	2.2	2.9	2.8	2.7	2.8	2.7	2.1	2.6
2	3.2	3.3	2.0	2.7	2.4	3.8	1.3	2.7	1.6	2.8	3.3	2.4	2.4	2.5	1.8	2.4
3	3.6	4.5	2.2	3.6	3.0	5.6	1.7	3.5	2.2	3.1	3.4	3.1	3.6	3.4	2.9	3.1
4	4.3	5.8	2.9	4.1	3.3	5.6	2.7	4.1	2.2	3.8	4.0	2.8	3.5	3.5	2.5	3.2
5	3.6	4.1	2.4	3.6	2.8	4.5	3.2	3.5	2.5	3.2	3.8	3.2	4.0	3.9	2.3	3.3
6	3.3	4.5	3.1	4.1	2.1	3.4	2.3	3.3	1.9	3.2	4.1	3.6	3.4	3.2	2.8	3.2
7	4.0	5.5	3.7	5.5	2.6	3.9	4.0	4.2	2.6	3.7	3.8	2.9	2.6	2.4	2.4	2.9
8	4.4	5.5	3.9	4.9	2.4	3.3	2.7	3.9	3.1	3.9	3.8	3.9	3.8	2.4	2.9	3.4
Average	3.7	4.7	2.8	3.9	2.7	4.3	2.5	3.5	2.3	3.3	3.6	3.1	3.3	3.0	2.5	3.0
	23	24	25	26	27	28	29	Weekly average	30	31						
1	2.6	5.6	4.1	2.8	1.7	1.7	1.9	2.9	1.6	3.7	----	----	----	----	----	----
2	2.9	5.5	4.0	3.2	2.3	2.1	1.8	3.1	1.8	3.9	----	----	----	----	----	----
3	3.7	6.6	5.2	3.7	3.2	2.4	2.8	3.9	2.7	4.9	----	----	----	----	----	----
4	3.3	6.3	5.0	----	----	----	----	----	----	4.3	----	----	----	----	----	----
5	2.4	6.8	5.8	3.4	2.4	1.9	2.3	3.6	1.8	4.5	----	----	----	----	----	----
6	2.5	4.8	5.5	3.9	2.5	2.6	3.5	3.6	1.7	4.4	----	----	----	----	----	----
7	3.1	5.5	5.3	2.9	1.6	1.3	1.9	3.1	1.5	5.0	----	----	----	----	----	----
8	3.2	5.1	6.5	4.0	1.9	1.8	2.2	3.5	1.7	4.4	----	----	----	----	----	----
Average	3.0	5.8	5.2	3.4	2.2	2.0	2.3	3.4	1.8	4.4	----	----	----	----	----	----

January 1940

Station No.	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Weekly average	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Weekly average
	Date								Date							
		1	2	3	4	5	6		7	8	9	10	11	12	13	
1	----	5.4	6.8	6.9	6.3	8.3	2.8	6.1	3.9	7.5	5.3	8.2	9.3	5.3	4.7	6.3
2	----	5.9	7.5	6.9	6.5	8.6	3.1	6.3	4.4	6.4	5.2	9.3	7.7	4.2	3.0	5.7
3	----	7.8	9.4	9.6	9.0	10.5	6.0	8.5	7.0	9.4	7.7	12.0	9.4	5.8	4.0	7.9
4	----	6.5	8.2	8.0	6.6	8.5	4.2	6.8	5.3	6.7	5.3	11.1	9.3	6.2	5.5	7.1
5	----	6.6	7.4	8.7	5.1	8.8	2.7	6.5	4.2	5.4	5.3	11.0	10.3	----	5.1	7.3
6	----	7.7	8.7	9.1	7.7	11.1	----	8.3	----	----	----	12.5	10.1	----	----	----
7	----	7.0	8.9	8.7	9.6	10.2	6.3	8.0	6.1	8.9	8.0	11.4	9.7	7.5	4.8	7.9
8	----	6.6	8.4	9.5	8.3	9.7	6.2	7.7	6.5	8.5	7.1	11.9	10.8	6.8	5.3	8.3
Average	----	6.7	8.2	8.4	7.4	9.5	4.5	7.2	5.3	7.5	6.3	10.9	9.6	6.3	4.6	6.3
	14	15	16	17	18	19	20	Weekly average	21	22	23	24	25	26	27	Weekly average
1	2.7	4.1	2.5	2.6	6.3	5.1	7.3	4.4	6.3	6.0	6.4	5.0	5.0	5.9	2.7	5.3
2	2.0	5.2	3.6	3.3	6.2	6.0	7.9	4.9	6.5	6.5	4.9	4.8	5.9	7.0	4.1	5.7
3	2.8	6.7	5.6	6.1	8.8	9.3	11.1	7.2	8.9	9.4	8.0	7.1	8.3	9.9	6.8	8.3
4	3.6	6.3	4.3	4.7	9.2	6.3	8.3	6.1	7.2	7.1	7.1	5.2	6.0	6.9	5.2	6.4
5	----	----	----	4.8	7.3	6.7	9.1	----	7.0	6.8	7.8	4.3	6.3	7.6	3.9	6.2
6	3.3	6.1	5.0	6.2	8.5	8.4	11.2	6.9	9.3	9.9	9.8	6.6	9.0	9.5	6.3	8.6
7	2.3	6.8	5.6	6.0	7.8	7.1	9.0	6.4	6.9	8.0	7.3	5.7	8.3	8.4	5.6	7.2
8	2.6	6.7	4.9	6.1	7.3	7.8	8.7	6.3	6.5	7.9	9.1	6.0	8.2	8.3	5.5	7.4
Average	2.8	6.0	4.5	5.0	7.7	7.1	9.1	6.0	7.3	7.7	7.6	5.6	7.1	7.9	5.0	6.9
	28	29	30	31												
1	2.7	6.1	6.5	4.5	----	----	----	----	----	----	----	----	----	----	----	----
2	3.3	6.2	6.5	4.7	----	----	----	----	----	----	----	----	----	----	----	----
3	6.3	8.0	8.0	6.5	----	----	----	----	----	----	----	----	----	----	----	----
4	3.4	6.4	7.3	5.7	----	----	----	----	----	----	----	----	----	----	----	----
5	4.2	7.8	7.8	5.4	----	----	----	----	----	----	----	----	----	----	----	----
6	6.1	9.6	9.0	6.1	----	----	----	----	----	----	----	----	----	----	----	----
7	5.2	9.8	9.4	6.1	----	----	----	----	----	----	----	----	----	----	----	----
8	5.4	8.5	8.2	5.4	----	----	----	----	----	----	----	----	----	----	----	----
Average	4.6	7.8	7.8	5.6	----	----	----	----	----	----	----	----	----	----	----	----

TABLE 3.—*Mean shade number by hour*

July 1939

Station no.	Hour											
	1	2	3	4	5	6	7	8	9	10	11	12
1	3.6	3.4	3.3	3.1	3.2	3.4	3.8	4.1	3.9	3.5	3.1	2.8
2	3.2	3.0	2.8	2.6	2.7	3.4	4.2	3.6	3.8	3.0	2.9	2.4
3	3.6	3.7	3.4	3.3	3.6	3.8	4.8	5.0	4.5	4.0	3.6	3.5
4	4.6	4.4	4.5	4.7	4.7	4.9	5.0	4.9	4.8	4.3	3.7	3.1
5	4.0	4.0	4.0	4.5	4.3	4.6	5.0	4.7	5.0	4.2	3.4	2.9
6	3.2	3.6	3.5	3.5	3.8	4.3	4.6	4.7	4.7	3.6	3.0	2.6
7	3.1	3.3	3.6	3.6	4.0	4.6	4.9	5.4	5.1	4.2	4.1	3.1
8	3.5	3.4	3.9	3.9	4.1	4.7	5.5	5.2	5.8	4.5	4.1	3.5
Average	3.6	3.6	3.6	3.7	3.8	4.2	4.7	4.7	4.7	4.3	3.5	3.0

Station no.	Hour												Monthly average
	13	14	15	16	17	18	19	20	21	22	23	24	
1	2.5	2.6	2.5	2.4	2.3	2.6	2.8	2.8	3.1	3.4	3.3	3.6	3.1
2	2.4	2.4	2.3	2.1	2.3	2.5	3.0	2.9	3.0	3.3	3.3	3.1	2.9
3	3.0	3.2	3.2	2.9	2.9	2.9	2.8	3.0	3.6	3.7	3.6	3.6	3.6
4	2.8	3.1	3.3	3.3	3.1	3.3	3.3	3.7	4.2	4.3	4.2	4.3	4.0
5	2.5	2.9	2.9	2.7	2.4	2.6	2.7	2.5	2.6	3.0	3.6	3.7	3.5
6	2.5	2.3	2.3	2.4	2.3	2.4	2.4	2 6	2.9	3.3	3.3	3.3	3.2
7	2.7	2.7	2.6	2.8	2.4	2.6	2.6	2.7	3.0	3.0	3.0	3.0	3.4
8	3.1	2.6	2.7	2.6	2.4	2.3	2.6	2.7	2.9	3.0	3.6	3.5	3.6
Average	2.7	2.7	2.7	2.6	2.5	2.7	2.8	2.9	3.2	3.4	3.5	3.5	3.4

January 1940

Station no.	Hour											
	1	2	3	4	5	6	7	8	9	10	11	12
1	4.6	4.4	4.6	4.7	4.7	6.3	6.6	6.8	6.6	6.0	5.5	5.2
2	4.3	4.5	4.4	4.4	4.6	5.8	7.4	7.2	7.4	6.7	6.1	5.6
3	6.3	6.4	6.3	6.3	6.8	8.3	10.2	10.6	10.0	9.5	8.6	8.0
4	5.3	5.6	5.6	5.4	5.9	6.3	7.8	8.2	8.6	7.6	6.9	6.9
5	6.7	6.6	7.5	6.7	7.4	7.5	8.6	8.3	8.1	7.2	6.3	5.9
6	7.3	7.2	7.4	7.8	8.5	9.4	10.5	9.9	9.4	8.9	8.6	8.0
7	6.3	6.2	6.3	6.5	6.8	7.5	9.1	9.9	10.3	9.4	8.7	7.9
8	6.9	6.6	6.4	6.5	6.7	7.2	8.2	8.7	9.2	8.9	8.3	8.0
Average	6.0	5.9	6.1	6.1	6.4	7.3	8.5	8.7	8.7	8.0	7.4	6.9

Station no.	Hour												Monthly Average
	13	14	15	16	17	18	19	20	21	22	23	24	
1	4.8	4.7	5.0	5.3	5.6	6.0	5.9	5.6	6.1	5.7	4.6	4.6	5.4
2	5.4	5.1	5.1	5.3	5.7	6.0	6.1	5.9	6.0	5.7	5.0	4.4	5.6
3	7.2	7.0	7.2	7.7	8.0	8.4	8.5	8.8	8.6	8.0	7.0	6.3	7.9
4	6.4	6.3	6.0	6.2	6.5	6.7	6.3	6.5	6.9	6.4	6.2	5.7	6.5
5	5.3	5.2	5.3	5.7	6.1	6.7	6.7	6.4	6.1	6.5	6.6	6.8	6.7
6	7.2	6.8	6.8	7.1	7.5	7.9	8.2	8.1	7.9	7.5	7.4	7.1	8.0
7	7.4	7.0	6.9	7.4	7.3	7.4	7.3	7.0	7.0	6.9	6.5	6.4	7.5
8	7.4	7.0	7.1	7.3	7.6	7.3	7.3	7.2	6.9	7.3	7.2	6.9	7.4
Average	6.4	6.1	6.2	6.5	6.8	7.0	7.0	6.9	6.9	6.8	6.3	6.0	6.9

TABLE 4.—*Mean shade number for each wind velocity*

July 1939

Station no.	Wind velocity—miles per hour							
	0	5	10	15	20	25	30	35
1	3.5	3.5	3.1	2.9	2.4	----	----	----
2	4.0	3.4	3.0	2.6	2.5	----	----	----
3	5.2	4.3	3.6	3.0	3.6	----	----	----
4	10.3	4.7	4.0	3.6	3.2	----	----	----
5	7.1	4.8	3.2	2.7	3.2	----	----	----
6	6.7	4.2	2.8	2.6	3.2	----	----	----
7	4.9	4.6	3.1	2.8	2.7	----	----	----
8	5.9	4.9	3.2	2.8	3.2	----	----	----
Average	6.0	4.3	3.3	2.9	3.0	----	----	----

Percentage of time wind is of given velocity

1-4	0.4	18.2	51.7	28.4	1.3	----	----	----
5-8	1.5	24.2	54.1	19.9	0.3	----	----	----

TABLE 4.—*Mean shade number for each wind velocity*—Continued

January 1940

Station no.	Wind velocity—miles per hour						
	5	10	15	20	25	30	35
1	7.8	6.0	5.1	3.7	3.1	*2.0	*1.3
2	7.8	6.0	5.4	4.3	2.9	*2.0	*1.3
3	11.1	8.2	7.7	6.3	4.9	*2.3	*1.0
4	9.4	6.9	6.2	5.0	3.9	*1.7	*1.3
5	8.9	7.1	5.6	5.7	5.3	*7.3	--------
6	10.2	8.5	7.4	6.6	4.8	*8.7	--------
7	10.0	8.1	6.8	5.3	3.1	*6.7	--------
8	10.4	8.1	6.6	5.4	4.1	*5.7	--------
Average	9.5	7.4	6.4	5.3	4.0	4.5	1.2

Percentage of time wind is of given velocity

1–4	6.4	40.9	38.9	12.2	1.3	0.2	0.1
5–8	7.5	46.3	36.9	7.7	1.4	0.2	--------

*Less than 10 readings.

TABLE 5.—*Mean shade number for each wind direction*

July 1939

For wind velocities below 7.5 miles per hour

Station No.	Wind direction							
	N.	NE.	E.	SE.	S.	SW.	W.	NW.
1	2.8	3.2	2.9	2.8	5.0	5.5	4.1	2.7
2	2.8	2.4	2.7	3.9	4.8	5.6	4.2	2.3
3	3.6	3.6	3.9	3.6	6.4	5.9	4.7	3.3
4	4.5	3.9	3.6	5.2	6.7	6.0	5.4	3.9
5	4.6	4.5	4.3	4.1	4.4	6.0	3.7	4.8
6	4.9	4.7	4.2	3.8	3.7	4.6	3.9	4.4
7	4.6	4.5	3.2	2.5	3.0	6.0	5.1	5.5
8	6.1	6.0	3.3	3.1	3.1	5.5	6.3	5.9
Average 1–4	3.4	3.3	3.3	3.9	5.7	5.8	4.6	3.1
Average 5–8	5.1	4.9	3.8	3.4	3.5	5.5	4.8	5.1

For wind velocities above 7.5 miles per hour

1	2.0	2.9	2.2	1.9	3.2	5.0	3.7	2.4
2	1.8	2.1	2.1	2.2	3.4	4.2	3.2	2.1
3	2.2	3.0	3.1	2.6	3.9	4.5	3.8	2.6
4	3.1	3.0	2.4	2.7	4.2	4.9	4.6	3.3
5	2.5	2.9	2.4	2.5	3.6	4.1	2.4	2.7
6	2.3	3.4	3.7	2.5	2.5	3.4	2.4	3.8
7	3.0	3.2	2.2	1.8	2.4	4.1	3.7	2.8
8	3.3	3.8	2.3	2.2	2.4	3.8	3.7	3.6
Average 1–4	2.3	2.7	2.5	2.4	3.7	4.6	3.8	2.6
Average 5–8	2.8	3.3	2.6	2.3	2.7	3.9	3.0	3.2

TABLE 5.—*Mean shade number for each wind direction*—Continued

July 1939—Continued

Percentage of time wind is from given direction

Station No.	Wind direction							
	N.	NE.	E.	SE.	S.	SW.	W.	NW.
1–4	10.9	6.0	16.5	9.2	19.7	15.5	9.9	12.3
5–8	4.6	12.0	3.7	20.6	15.9	25.0	5.8	12.4

January 1940

For wind velocities below 7.5 miles per hour

Station No.	Wind direction							
	N	NE	E	SE	S	SW	W	NW
1	6.9	7.7	8.9	*8.0	--------	--------	*6.8	7.8
2	7.8	7.1	8.3	*8.5	--------	--------	*8.4	7.9
3	8.5	11.6	11.7	*13.0	--------	--------	*8.8	11.4
4	10.3	8.9	10.9	*10.5	--------	--------	*7.6	9.5
5	8.7	8.3	8.5	--------	--------	*9.0	9.6	*8.1
6	10.4	*12.2	*12.4	--------	--------	*9.1	10.1	*9.1
7	11.3	9.7	9.1	--------	--------	*8.4	10.3	*10.2
8	11.0	10.4	10.6	--------	--------	*8.7	10.1	*11.3
Average 1–4	8.4	8.8	9.9	10.0	--------	--------	7.9	9.1
Average 5–8	10.3	10.1	10.1	--------	--------	8.8	10.0	9.7

For wind velocities above 7.5 miles per hour

1	5.0	5.7	5.7	*4.2	4.7	7.3	5.8	4.2
2	5.2	4.7	4.2	*7.2	5.7	7.5	6.3	4.8
3	7.3	6.6	5.8	*5.0	6.0	9.7	8.6	7.6
4	5.8	6.1	6.3	*4.6	6.0	8.3	7.1	5.5
5	5.3	6.5	7.6	*4.0	--------	8.4	7.8	4.8
6	7.1	7.3	6.6	3.7	*2.6	8.8	9.0	7.1
7	7.2	6.8	5.6	2.7	*2.3	8.3	8.3	6.6
8	6.6	7.5	6.6	2.8	*2.9	7.6	7.9	6.6
Average 1–4	5.8	5.8	5.5	5.3	5.6	8.2	7.0	5.5
Average 5–8	6.5	7.0	6.6	3.3	2.6	8.3	8.2	6.3

Percentage of time wind is from a given direction

1–4	19.5	12.2	8.3	0.5	0.8	5.3	27.9	25.5
5–8	13.8	11.4	9.3	0.7	0.5	4.4	35.6	24.3

* Less than 10 readings.

THE DUST SPECTRUM